Modeling of Air-Sea Interaction and Ocean Processes for the Northern Arabian Sea Circulation – Autonomous Research Project

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LONG-TERM GOALS

Our overall goal is to understand and quantify the upper ocean physical processes that determine the air-sea interaction, mixed layer dynamics, ocean circulation dynamics and space-time variability in the Northwestern Indian Ocean and Arabian Sea on time scales from days up to several seasonal cycles.

OBJECTIVES

(1)   provide modeling support, including real time coupled atmosphere-ocean-wave forecasts from COAMPS, to support planning and sampling strategies of new observational studies in the Office of Naval Research - Department Research Initiative NASCar: Northern Arabian Sea Circulation – Autonomous Research;

(2)   provide collaboration and model solutions to the NASCar Science Team to help interpretation and analysis of NASCar observations;

(3)   determine the mechanisms causing vertical mixing in the Arabian Sea: wind mixing, role of air-sea interaction and surface heat and fresh water fluxes, surface waves and shear induced mixing at the base of the mixed layer depth;

(4)   provide an investigation of the interaction between the Somali Current and its eddies and its three-dimensional structure and variability, and its connection to the Arabian Sea circulation, with focus on the equatorial region and the East African Coastal current, a source of low-salinity water for the Arabian Sea.

APPROACH

The fast-flowing Somali Current and its intense eddies, especially during the mature phases of the monsoons, are a challenge to observe due to their high spatial and temporal variability. It is in the northwestern Indian Ocean, an area with few in-situ observations but very high intra-seasonal variability due to the Asian monsoons, incoming Rossby waves and instability of western boundary

currents. The fast-flowing Somali Current and its intense eddies during the mature phases of the monsoon is a key to the circulation in the northwestern Indian Ocean and Arabian Sea NASCar will make use of autonomous vehicles, such as drifters, floats and gliders, as well as remote sensing and numerical models to advance our understanding of the physical oceanography in this region. The role of the proposed research in this DRI is to provide comprehensive numerical modeling support for planning, launching and interpretation of the observations made during NASCar. This task will be done using the Navy's Coupled Ocean-Atmosphere Mesoscale Prediction system using high-resolution submodels of the atmosphere, ocean and wave field. The models will include 3Dvar data assimilation of meteorological and oceanographic observation and will be used to produce hindcasts and forecasts up to 5 days. The hindcast models will be run during NASCar to help interpret observations by the Science Team. The model simulations will also be analyzed to determine the physics and underlying dynamics of the air-sea interaction, circulation and mixing of the Arabian Sea and its interdependence of adjacent waters. This will include mass, salt and heat budget calculations for selected regions of the Arabian Sea.The models will be used to:

a) Isolate the most important physical processes, locally and remotely forced, that control the seasonal reversal of the circulation of the Arabian Sea

b) Provide predictions and real time forecasts to plan and guide autonomous observations

c) Include autonomous observations in model validation and analysis for improved predictability.

The Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) coupled to the Navy Coastal Ocean Model (NCOM) and the Simulating Waves Nearshore (SWAN) spectral wave model via the Earth System Modeling Framework (ESMF) is used for this work. It is a state-of-the-art modeling system developed at NRL.

WORK COMPLETED

For NASCar we completed the configuration of a fully coupled atmosphere-ocean-wave NASCar-COAMPS model. The atmospheric component has 60 vertical levels. The ocean model has a 0.5m resolution in the upper 10 m, 45 sigma levels and up to 15 z-levels for a total of 60 levels in water deeper than 330 m. The spectral wave model (SWAN) has 33 frequency bands and 48 directions. Coupling interval for the models is 6 min. The ocean model includes 8 semi-diurnal and diurnal tidal components. The numerics apply 3rd order upstream differencing schemes, 4th order pressure gradient and Coriolis terms for increased accuracy. The turbulent close scheme is the Kantha-Clayson 2.5 closure scheme that includes Stokes drift from the wave model. Boundary conditions for the atmosphere is from the NAVy Global Environmental Model (NAVGEM) and for the ocean from the global Hybrid Coordinate Model (HYCOM). Observations are included in the atmosphere and ocean models using the NAVy Data Assimilation System (NAVDAS), a 3-dimensional data assimilation system for the atmosphere and 3dVAR-Naval Ocean Data Assimilation (NCODA) for the ocean. The wave model is not assimilating data. The NASCar-COAMPS was ported to the IBM iDataPlex supercomputers at the Navy DSRC. Initial problems with model stability were solved by changing the model from single precision to double precision for the atmosphere and ocean components and increasing the available memory per compute node.

The NASCar-COAMPS coupled regional model area covers the western Indian Ocean north of 18°S, eastward to 80°E with a horizontal resolution of about 3.5 km in the ocean and 9 km in the atmosphere.

The coupled COAMPS has been run daily in a hindcast mode with 1-day delay to accommodate data assimilation. It is also configured to run up to 5-days forecasts in real time during the NASCar observational period. The NRL website is updated daily and provides daily averages of 10-m winds, sea surface height, sea surface temperature, sea surface salinity, and net surface heat flux. The surface fields are available since the start of the run on April 1, 2015. The password protected web site URL is https://www7320.nrlssc.navy.mil/NASCar/ (userid and password available upon request from the PI). The website has been approved for public release.

Standard output from COAMPS is archived on the DSRC. Those are hourly output of near-surface meteorology, surface fluxes and sea surface height, temperature, salinity, currents, significant wave heights, average wave periods and wave lengths. Subsurface ocean fields will be provided on a 3-hourly interval. These includes temperature, salinity, velocity and Stokes drift. The ocean model component COAMPS-NCOM has recently been modified to write out the vertical velocity field in addition to the horizontal component. This allows for 3D advection of Lagrangian tracers from model output. Another recent capability is the option to write out turbulent kinetic energy (TKE), turbulent length scale, eddy viscosity and eddy diffusion to diagnose vertical mixing.
To facilitate use of COAMPS model output by NASCar Science Team members it is proposed that a data server located at a university will be used. We can upload time-averaged fields at selected depth to this server.

In addition to the NASCar region a similar model has been set up for the Bay of Bengal. This coupled model ASIRI-COAMPS has the same vertical resolution in the atmosphere and ocean model components and same spectral resolution in the wave model. The horizontal resolution is higher in the atmosphere (18km with 6 km inner nest) and in the ocean (2 km) and slightly lower for waves (13 km). The model domain starts at 70°E to 100°E and covers the area from 1.5^{o}S to 23°N. There is an overlap with the NASCar region north of 1.5^{o}S between 70°E to 80°E, which connects the Arabian Sea and Bay of Bengal areas. This provides the modeling of the direct connection between these two marginal seas. Future plans include combining these too models into a larger model that includes most of the Indian Ocean basin. This model has been run daily since June 1, 2015 and daily surface fields as above are available at https://www7320.nrlssc.navy.mil/ASIRI/ (userid and password available upon request from the PI). The website has been approved for public release.

RESULTS

We find strong air-sea interaction over the Somali Current. Winds decrease over the cold water upwelling wedges north of the Great Whirl and surface winds are decreased due to less turbulence in the atmospheric planetary boundary layer. Fig 1 show the decrease in 10-m winds over the cold upwelling regions associated with the Great Whirl. The decreased winds results in lower significant wave heights (Fig. 2) and over the cold water, net surface heat flux into the ocean is increased. These results show the clear advantage of a fully coupled system. The momentum and heat flux exchanges between the models component are consistent with what is observed in nature. For forced uncoupled models this is often not the case.
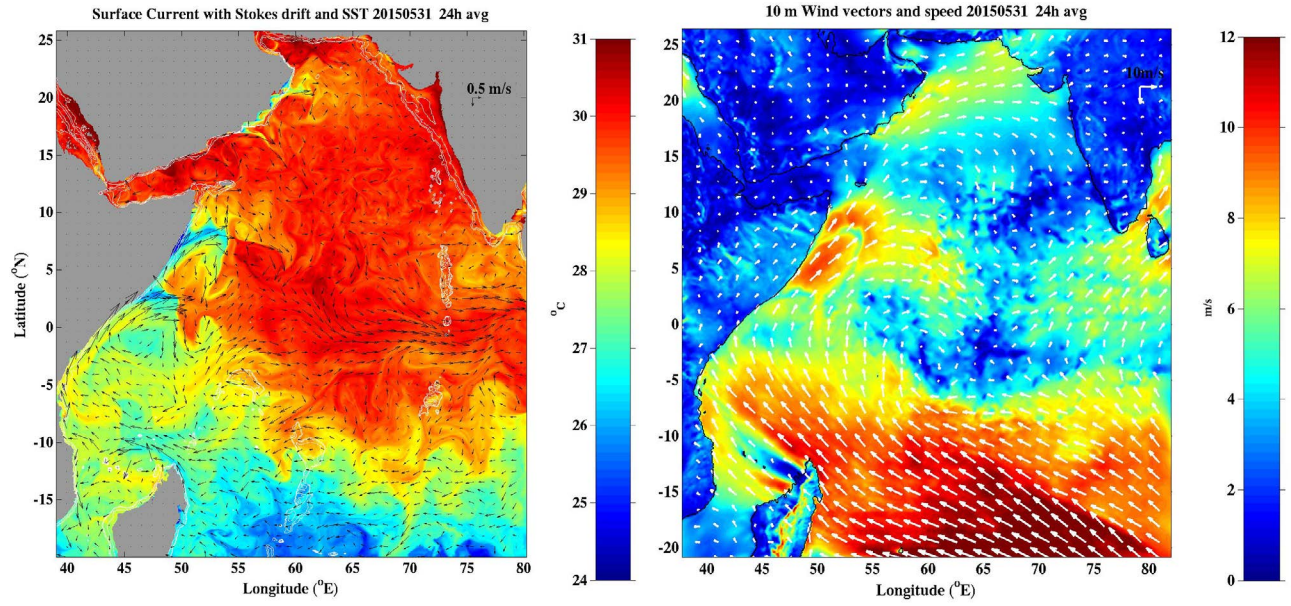
Fig. 1. Sea Surface Temperature (SST) from NASCar-COAMPS on May 31, 2015 (left) and 10-m wind vectors and speed. Note that wind speed is lower over cold upwelling regions than in areas with high SST. Plots show daily averages.
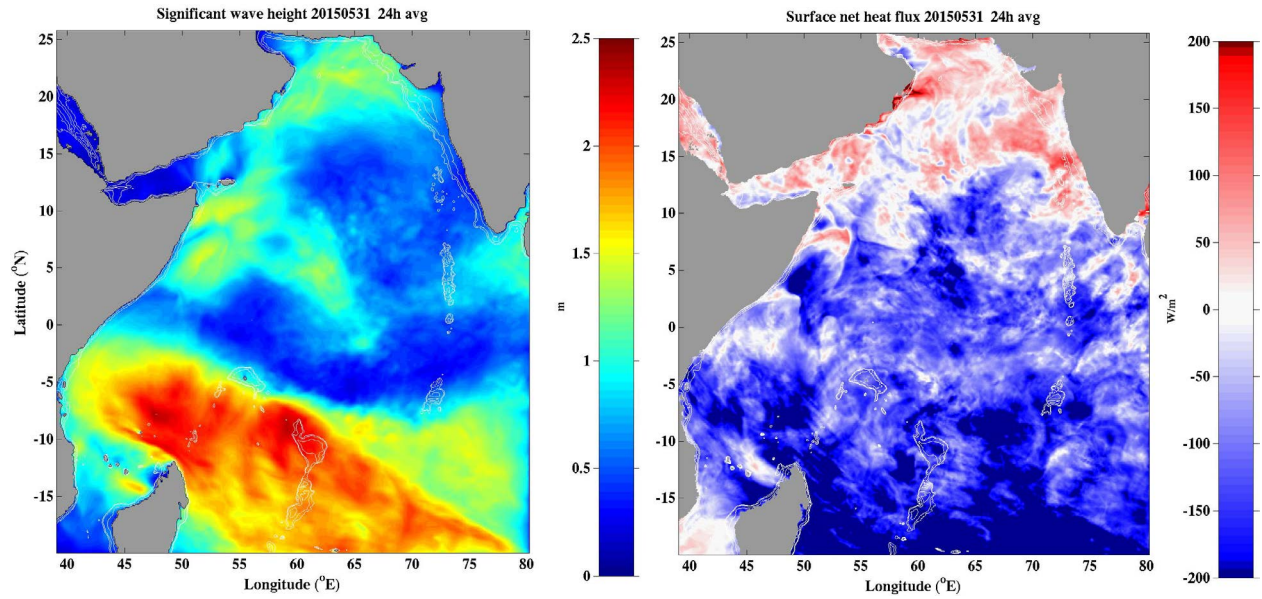

Fig. 2. Significant wave height (left) from NASCar-COAMPS on May 31, 2015. Note the reduced significant wave height in the cold water wedge north of the Great Whirl where wind speeds are reduced. Unit is meters. Right: Net surface heat flux into the ocean. Unit is W/m². The plots also show the entire COAMPS-NASCar coupled model domain.
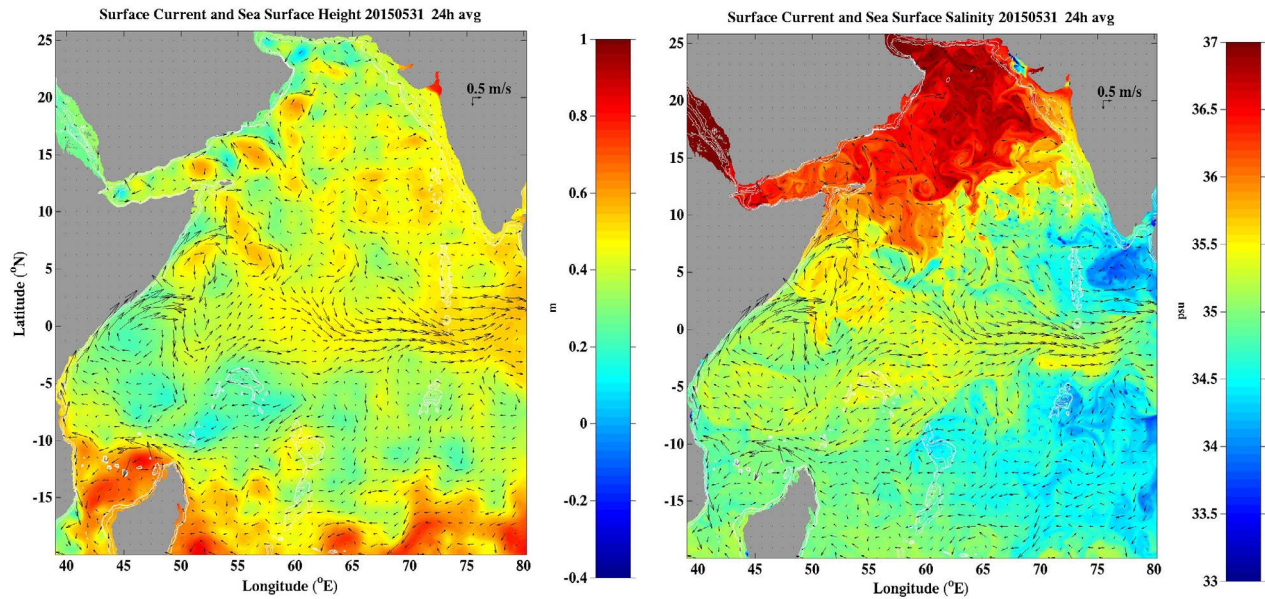
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Fig. 3. Sea surface height (left) from NASCar-COAMPS on May 31, 2015. Unit is meters. Right: Surface salinity.Unit is psu.

IMPACT/APPLICATIONS

The project contributes to the better understanding of the connection of the Somali Current system to the interior circulation of the Arabian Sea, the equatorial wave guide and the boundary currents in southern Indian Ocean. Better understanding of the short term circulation, stratification and Lagrangian pathways is applicable for Navy ship operations, ASW and search and rescue.

RELATED PROJECTS

This project is related to the NRL EBoB project and the ONR ASIRI project that adress the circulation and mixing in the Bay of Bengal as discussed above.

PUBLICATIONS

Jensen, T. G. and D. S. Ko (2014): West Indian Ocean Model (WINDO). Website: www.7320.nrlssc.navy.mil/NLWI_WWW/WIND_WWW/

Jensen, T. G., D. S. Ko and H. Wijesekera (2014): Inter-annual variability of currents, temperature and salinity during 1998-2012 in a high-resolution ocean model of the western Indian Ocean. Poster Session and abstract. American Geophysical Union, Fall meeting, San Francisco, Dec 15-19, 2014

Jensen, T. G. and D. S. Ko (2015): NASCar-COAMPS nowcast. Password protected website: https://www7320.nrlssc.navy.mil/NASCar/

Jensen, T. G., H.W. Wijesekera and D. S. Ko (2015): NASCar-ASIRI nowcast. Password protected website: https://www7320.nrlssc.navy.mil/ASIRI/